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Normalizing Deviance: 30 Years After the Challenger Explosion

Introduction

Safety is the number one priority at Albemarle. Unfortunately, safety and environmental incidents do still happen in our industry, but when they do, learning from those incidents is critical to ensuring that they never happen again. We believe that sharing those lessons learned with others in the industry will help keep us all safer. To that end, a recent incident involving Normalization of Deviance is presented below.

Normalization of Deviance (NoD) is a concept developed by Dr. Diane Vaughan following the 1986 Space Shuttle Challenger disaster. While the concept has been frequently discussed over the last 30 years, the author questions whether industry has addressed the issue on all fronts. A significant NoD incident within Albemarle Corporation was motivation to fully explore the original concept. The intent of this paper is to highlight the potential gaps in understanding of Normalization of Deviance, to suggest possible avenues to close the gaps, and to solicit industry-wide effort to develop meaningful programs.

Albemarle Incident

On August 3, 2014, Albemarle's Magnolia, AR site had a failure in the tangent of a bottom nozzle on a jacketed, glass-lined "reactor" (R-102). At the time of the release, the vessel contained a significant amount of bromine, solid product, and water. The entire content of the vessel was released. Fortunately, passive mitigation safeguards were in place that collected the majority of the bromine in a process water sump. Since bromine has a specific gravity of 3.0, it forms a separate phase beneath water and fuming is essentially eliminated. Still, during the release there was evaporation from the stream of bromine that flowed between the vessel and the sump. It is estimated that 10% of the material was released to the air over a period of 60 minutes. As soon as the problem was identified, Albemarle reacted quickly. Personnel at the site were required to shelter-in-place and no one was exposed to the release. The vapor cloud did not leave the site boundaries.

Albemarle's safety protocols require that a thorough investigation be conducted. The Magnolia site processes many highly corrosive chemicals and typically uses glass-lined steel vessels in processing. The Albemarle Engineering Standards require glass-lined steel vessels to be manufactured and supplied as "plug-free[1]". Though plugs are not allowed in purchased vessels, tantalum patches and teflon nozzle sleeves are allowed in the vapor space of in-service vessels. As an added safeguard, vessels that have been repaired in this fashion are required to have an internal inspection at least every 6 months. R-102 had both a tantalum patch and a nozzle sleeve in the vapor space of the vessel.

Approximately one year prior to the incident, a "fish-eye" was noted during a routine internal inspection of R-102. A "fish-eye" is an occlusion or imperfection in the glass lining. In this case, the area of concern was in the tangent on the bottom nozzle of the vessel. The inspector identified the issue, performed a spark test[2] to verify glass integrity and noted the issue in his report. Since the vessel passed all of the inspection parameters, it remained on a six-month inspection schedule. Similarly, there were no issues noted during the next inspection.

Less than 3 months prior to the failure, the process experienced a quality excursion that suggested the glass may be compromised. Knowing the recent inspection history of R-102, Operations Management shutdown the process and requested an early internal inspection of the vessel. The inspector performed another spark test but did not identify any issues. The source of the process issue was later found and corrected. It was not associated with R-102.

As mentioned, Corporate Engineering Standards allow the use of tantalum patches in the vapor space of glass-lined vessels with the requirement that the internal inspection frequency be increased to at least twice per year. Even with these highly corrosive chemicals, the risk is deemed low in most instances due to the location of the patches and the corrosion rate of the chemicals. The location is important because the severity of a release is mitigated in the vapor space. Since these vessels run at lower pressures (~30 psig), a release from the vapor space could be managed and would occur at a much lower mass rate than a liquid release. The corrosion rate of the chemical is important because the primary safeguards are the inspection interval and the ability to detect iron (glass failure) through sampling measures.

Inherent in any inspection interval is the belief that problems can be identified and repaired prior to experiencing significant damage to the vessel. In most of the Magnolia bromine processes, these safeguards are effective because the corrosion rate of mild steel is quite low[3] if the bromine is dry[4]. Therefore, should glass failure occur, the dry bromine will cause a gradual corrosion mechanism that could be reasonably detected by the inspection and sampling measures.

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[1] If there are small defects in the glass lining, suppliers may choose to repair the issue rather than reglass the entire vessel. The repair is made by drilling a hole through the glass and into the carbon steel metal. A corrosion resistant (usually tantalum) plug is then inserted into the hole.

[2] A spark test is an inspection technique to verify the integrity of a non-metallic liner. A metal brush with approximately 5,000 V DC is swept along the surface of the liner. If metal is contacted, a spark will occur.

[3] At 1.2 ppm water, test data suggests that liquid bromine corrodes mild steel at a rate of 0.0085 inches per year.

[4] These systems are inherently dry because bromine is mixed with oleum or aluminum chloride.

Unfortunately, the same is not true for R-102. Water is purposely added to the mixture of bromine and solid product in this vessel. Once the water has been added to the system, the bromine becomes saturated with water and the corrosion rate changes significantly[5]. In fact, it is estimated that should the glass liner fail in this service, the steel shell will be compromised within 4 days.

In retrospect, the Magnolia plant should have stopped the operation of R-102.

- The location of the fish-eye was "worst-case". In the tangent of the bottom nozzle, a failure would immediately allow chemicals to be released to atmosphere, the release would be liquid, and the release would be uncontrolled – a complete loss of the vessel contents.
- The wet bromine service ensured a high corrosion rate; a rate that rendered the two safeguards useless. There was not enough time to detect and respond.

The work group did not see this situation as abnormal when compared to other vessels. It was common to use inspection frequency and sampling measures to monitor the existing patches. So, they followed the "normal" course of action. It is a necessary characteristic of Normalization of Deviance that the work group is blinded to their folly. In investigating the Challenger incident, Dr. Diane Vaughan looked not only at how performance was normalized but also at the striking disparity between post-accident investigator's labeling of NASA actions as deviant while the Engineers involved in these same actions considered them normal and acceptable when they occurred (1).

In the Magnolia incident, it can be argued that no systems failed and no direct error was made. It was a lack of identification and lack of action by a group of people that created the circumstances. It was this work group blindness that propagated Normalization of Deviance. The remainder of this paper is intended to further investigate this issue. However, for completeness, Appendix A includes an example of a glass repair matrix that was developed to address the specific incident discussed above.

<u>Challenger Disaster</u>

[5] While it is unreasonable to test such conditions, interpolation of existing data suggests the corrosion rate may be 100 inches per year at 650 ppm water.

On January 28, 1986, the space shuttle Challenger exploded resulting in the death of seven crew members. The primary causal factor was identified to be hot gas bypass of both the primary and secondary O-rings on the Solid Rocket Boosters (SRB) that impacted and penetrated the external fuel tanks (2). It is believed that unusually cold weather in Florida, in the 24 hours preceding the launch contributed to the O-ring failure (2). Figure 1 shows the design of the tang and clevis construction of the SRB joints and the role that the two O-rings played in separating the burning propellant from the exterior of the shuttle.

Figure 1:
Presidential Commission Report on the Space Shuttle Challenger Accident, Figure 14, p. 58

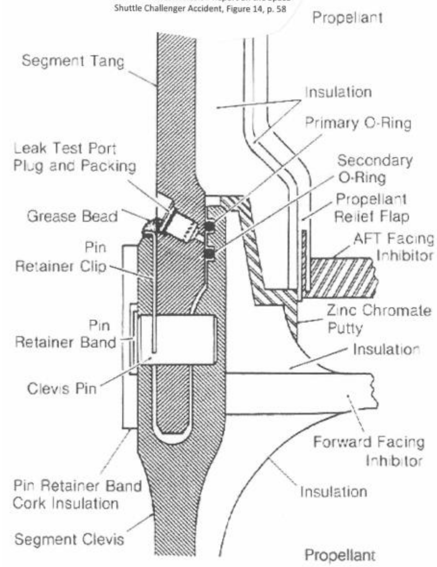


Figure 1.
Solid Rocket Motor cross section shows positions of tang, clevis and O-rings. Putty lines the joint on the side toward the propellant

The potential for O-ring failure was a known problem. In fact, managers and engineers at NASA's Kennedy Space Center, NASA's Marshall Space Flight Center, and Morton Thiokol (the contractor for construction of the Solid Rocket Motor) were all aware of the problem and participated in a late night meeting on January 27 to discuss the possibility of O-ring failure due to cold weather (1).

The subsequent investigations into the incident revealed that the concern about potential O-ring problems had been identified *prior to the first space shuttle launch*. Such damage was tracked after each of the 27 flights prior to the Challenger incident. Following the incident, many people proposed reasons for NASA launching with known O-ring issues. In the Presidential Commission report, Dr. Richard Feynman suggested that safety was compromised to meet schedule requirements.

> If a reasonable launch schedule is to be maintained, engineering often cannot be done fast enough to keep up with the expectation of originally conservative certification criteria designed to guarantee a very safe vehicle. In these situations, subtly, and often with apparently logical argument, the criteria are altered so that flights may still be certified in time. They therefore fly in relatively unsafe condition, with a chance of failure of the order of a percent (2).

Another common reason given was that in considering a flight delay due to cold weather, NASA set an unreasonable expectation for engineers by requiring them to prove a failure was imminent. This belief is likely grounded in post-event comments by Thiokol engineers that on the night prior to the fatal launch, <u>they</u> (Thiokol) were put in a position requiring them to validate a no-fly position due to the past development of risk tolerance – a risk tolerance previously developed and supported by Thiokol (2). In other words, Thiokol had previously supported launching even when O-ring damage was expected. The night before the Challenger launch Thiokol engineers were required to convince everyone (NASA, Marshall, and Thiokol) that previous Thiokol flight readiness recommendations had been wrong.

As detailed in Vaughan's book, *The Challenger Launch Decision - Risky Technology, Culture, and Deviance at NASA*, both of these are very simplistic models of the issues associated with the incident. Even the engineers who were arguing against a launch did not *believe* the SRB would fail; they were merely concerned about operating at conditions that increased risk. With one exception, they did not believe a complete burn-through of both O-rings was possible (1).

So, what was the reason for the poor decision to launch? In *The Challenger Launch Decision*, Vaughan introduced the concept of Normalization of Deviance (NoD). Her detailed investigation identified three areas that combined to allow NoD to be established and maintained - the production of a work group culture, the culture of production, and structural secrecy.

<u>Production of work group culture – "How did we get here"</u>

Vaughan's description of the "production of work group culture" is the common industry concept of Normalization of Deviance. Simplistically, it can be considered the "How did we get here?" aspect. It is the procession of actions and decisions that lead groups into "normal" work processes that are unwise. For the Challenger's Solid Rocket Booster (SRB) work group, this began with the initial design of the motor and a belief in redundancy.

The beginning premise of the SRB work group was that their joint design was safer than the respected and proven Titan rocket design (1). It was safer because an additional O-ring had been added and was considered to be a redundant safeguard. During testing, prior to any shuttle launch, the SRB joint deviated from the designed performance (1). The tang and clevis connections deflected and allowed the O-rings to unseat. The engineers involved followed NASA procedures and treated the deviation as a signal of potential danger – documenting and reporting it as required. However, since the joint design was unique, there was no precedent for responding to the problem.

The production of work group culture was a sequence of actions that began with an unexpected problem (joint deviation) that had no defined solution. Vaughan identified five steps in the sequence of events that were integral to the production of work group culture.

1. Signals of potential danger
2. Official act acknowledging escalated risk
3. Review of evidence
4. Official act of normalizing the deviation – accepting risk
5. Shuttle launch

After tests revealed the joint deviation, the work group devoted time and resources to further investigate and test both the O-rings and the joint dynamics. Ultimately, when the group reviewed the evidence, they believed that the primary O-ring could only fail in a worst-case scenario and they believed that the secondary O-ring would be available as a backup, should this unlikely event occur (1).

Next, the work group presented its findings through NASA's four-tiered review process where the joint was eventually certified as flight-worthy by the Verification and Certification Committee. By declaring the joint deviation as accepted and expected performance of the shuttle, the work group's construction of risk became the official NASA organizational construction of risk. This process is similar to that experienced in the chemical industry after scenarios are identified in a Process Hazard Analysis (PHA) or Layer of Protection Analysis (LOPA). The PHA team will meet with site or corporate management to review the significant scenarios and discuss whether safeguards are sufficient to meet the company's risk tolerance.

Finally, since no problems were found after the first mission, the official construction of risk and the SRB work group's technical justification was confirmed. In subsequent flights, when primary O-ring damage was found, the response was to attempt to improve O-ring performance rather than redesign the joints.

Thus, the system was primed for repeated rounds of identification, escalation, and acceptance of risk. Also, O-ring damage became an expected result of flight rather than an anomaly. Vaughan describes the situation as follows:

> The significance of the above sequence of events lies not in its initial occurrence, but in its repetition. Decision making became patterned. Many times in the shuttle's history, information indicated that the O-rings deviated from performance expectations, thus constituting a signal of potential danger. Each time, the above decision sequence occurred. The connection between some incident in the past and the present is demonstrated when it is repeated. Patterns of the past – in this case, decision-making patterns pertaining to technical components – constitute part of the social context of decision making in the present. This decision-making pattern indicates the development of norms, procedures, and beliefs that characterized the work group culture (1).

<u>The culture of production – Why did we stay there?</u>

Vaughan called the second area that contributed to Normalization of Deviance in the Challenger incident, "the culture of production." Simplistically, it can be considered the, "Why did we stay there?" aspect. For the purposes of the Challenger investigation and this paper, "the culture of production" can be assumed to be referring to Engineering and Technical Management culture. Vaughan uses Thomas Kuhn's *The Structure of Scientific Revolutions* as a reference for much of the assessment of culture. For simplicity, this will be referred to as engineering culture.

Engineering culture follows specific rules that are based on experience. Any number of codes and standards could be cited to support this statement. Alternately, when a situation arises that is unique; since there are no established rules, the rules will follow the evolving practice. When technology develops in ways not covered by existing codes, standards, or procedures, Engineers must create informal expectations. These informal expectations become a paradigm; a typical and accepted pattern. In other words, once the informal expectation is accepted, it becomes "experience" and will become the pattern for addressing the situation. In fact, according to Kuhn, normal science does not aim to break the paradigm but only to support it. Any event or circumstance that does not fit the paradigm is often not seen at all (3).

For the SRB team, once the O-ring concern was voiced, defended as an acceptable risk by the Engineers, and accepted in Flight Readiness Reviews by NASA leaders, it became the accepted paradigm (1). Once established, the paradigm became the basis for future decisions. Engineers described Flight Readiness Reviews as technically intimidating situations. Presenters understood that statements like, "I think" or "I feel" would draw the wrath of superiors. Only data-based, engineering-supported positions were acceptable for presentations (1). For these reasons, the fact that the group continued to recommend launch, while at the same time worrying about the long term viability of the O-ring system, made sense within the Engineering culture.

According to Kuhn, the difficulty in overturning a scientific paradigm is due to the worldview it creates; it is overturned when a crisis arises that causes a transformation of that worldview (3). So, unique situations lead to new paradigms that, if poorly constructed, can lead to blind compliance in an unsafe situation. Normally, in these cases, a crisis is required to break the paradigm and transform the rules of "normal" science. Such a crisis could be a large bromine release or the explosion of a space shuttle.

Structural Secrecy – "Why didn't someone stop us?"

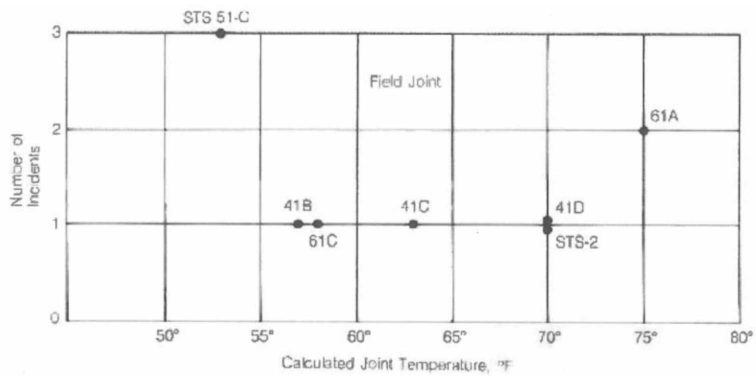
The third area that contributed to the Normalization of Deviance in the Challenger incident is referred to as "structural secrecy." Vaughan describes structural secrecy as the way organizational structures can inhibit the transfer of information that provides the desired knowledge. This is particularly true for large organizations like NASA since most actions are not observable. Simplistically, it can be considered the, "Why didn't someone stop us?" aspect.

Specialization inhibits knowledge transfer because people in different departments lack the expertise to understand the work of others or appreciate its impact on their area of responsibility. Language used in tasks or used to describe incidents can be incredibly vague due to acronyms and jargon. Changing standards and technology also inhibit knowledge because of the difficulty in keeping up of the latest developments while also attending to primary job duties.

In an effort to overcome this issue, companies find formal ways to transmit complex information with the belief that knowledge will also be conveyed. Ironically, this can result in less knowledge transfer. Fine distinctions disappear in standardized forms. More importantly, the amount can increase to the point that much is not read and the whole enterprise serves as more symbolic than true communication. In Vaughan's words, "Obfuscation parades as clarity: they produce too much, obscuring rather than enlightening" (1).

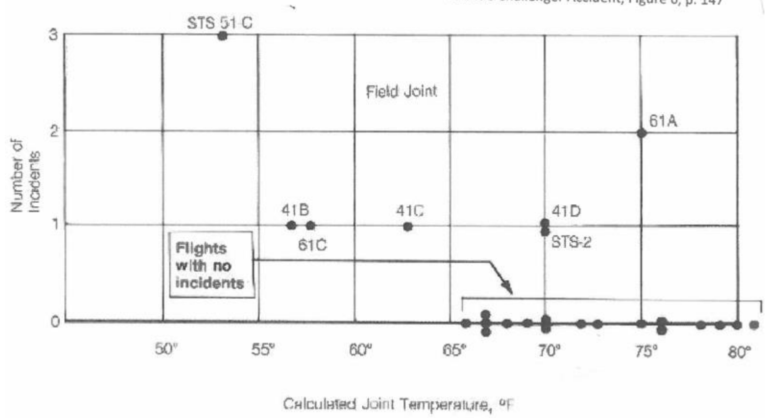
Companies respond to this excessive information by developing a formal program that reduces the amount that flows to the top decision makers. This is necessary to ensure that certain information receives adequate attention. Unfortunately, information can be lost in this distillation process leading to uncertainty. Uncertainty can lead top decision makers to rely on signals to simplify the issues. However, as can be seen with the Challenger incident, signals do not always ensure knowledge transfer.

Vaughan identified three types of signals that impeded knowledge transfer with regard to the Challenger's O-rings. Since the information was accumulating over a long period of time, it looked very different to the work group than it did to the post-accident investigators.



Plot of flights with incidents of O-ring thermal distress as function of temperature

Figure 2:
Presidential Commission Report on the Space Shuttle Challenger Accident, Figure 6, p. 147



Plot of flights with and without incidents of O-ring thermal distress

Figure 3:
Presidential Commission Report on the Space Shuttle Challenger Accident, Figure 7, p. 147

- Signals were mixed – Signals of trouble were interspersed with signals that problems had been solved. In addition, every time the SRB work group made a presentation, prior to a launch, they were simultaneously announcing O-ring concerns while supporting flight readiness (1). For this reason, the concern was mollified, documented, and accepted.
- Signals were weak – The information was ambiguous and the threat was not clear (1). When the need arose on night before the Challenger launch, it proved to be impossible to topple the risk paradigm because the cold weather concern was not supported by "solid" evidence or data. As can be seen, Figure 2 does not show a correlation between temperature and O-ring thermal distress. Therefore, it was ineffective at convincing people that a no-fly recommendation was necessary. Figure 3 was developed post-accident and includes launches without O-ring issues. This gives a much stronger signal that temperature should be a concern.
- Signals were routine – For the entire Space Shuttle organization, O-ring erosion became a frequent and predictable result of shuttle service (1).

Applications of Vaughan's Model

Dr. Vaughan's model for Normalization of Deviance has several implications for the chemical industry. First, NoD is typically only associated with the Production of Work Group Culture aspect. This is the "How did we get here?" aspect of NoD. The tools typically use to prevent this type of issue are the base systems associated with a strong process safety program. These include Process Hazard Analysis, Management of Change, and Procedures/Standards. If these programs are 100% effective, they should prevent a NoD situation from occurring. Unfortunately, it is unlikely, if not impossible, for these programs to perform perfectly. Since NoD situations lead to situational blindness for those participating in the work group, we must also concentrate on the other two aspects.

Systems to break paradigms and improve knowledge transfer are not a part of a traditional process safety program. In fact, rather than an engineering aspect, these topics fall into the realm of psychology. Therefore, rather than looking to industry-wide management systems, the decision was made to investigate High Reliability Organizations (HRO). It was assumed that the same attributes that define a successful HRO would be attributes to combat Normalization of Deviance.

Concepts on High Reliability Organizations

Traditionally, the concept of a High Reliability Organizations (HRO) has been tied to proven performance. An HRO was a company that displayed a high level of safety over an extended period of time (4). A more modern definition of a High Reliability Organization is tied to probability of catastrophe. In this model, an HRO is a company that must constantly manage catastrophic risk in order to meet the demands of the business (5).

In *Managing the Unexpected, Sustained Performance in a Complex World*, Karl E. Weick and Kathleen M. Sutcliffe provide a quote from Gene Rochlin that may be more familiar to those working in the chemical industry.

> High reliability organizations (HROs) "seek an ideal of perfection but never expect to achieve it. They demand complete safety but never expect it. They dread surprise but always anticipate it. They deliver reliability but never take it for granted. They live by the book but are unwilling to die by it…" (5)

In *Managing the Unexpected*, Weick and Sutcliffe attribute the superior performance of HROs to five factors.

1. Preoccupation with Failure
2. Reluctance to Simplify
3. Sensitivity to Operations
4. Commitment to Resilience

5. Deference to Expertise

Preoccupation with Failure

Preoccupation with failure describes a company that is continually looking for system deviations that could be symptoms of larger problems. There are three areas where preoccupation with failure is needed (5).

1. Detecting small, emerging failures that may be clues to additional failures elsewhere in the system. Many companies address this area with leading process safety metrics.
2. Anticipating significant mistakes that need to be avoided. This area is the purpose of qualitative risk assessments such as Process Hazard Analyses.
3. Understanding that people's knowledge of the situation, the environment, and their own group is incomplete. This is the area of the "culture of production" that Vaughan describes. Weick and Sutcliffe explain, "Success narrows perceptions, changes attitudes, reinforces a single way of doing things, breeds overconfidence in current practices, and reduces acceptance of opposing points of view (5).

This third area of "preoccupation with failure" is sometimes referred to as a "sense of vulnerability" in Process Safety culture surveys. According to researchers, it may be absolutely necessary for making rational risk decisions. Psychologist Dr. Daniel Kahneman writes about an affect heuristic where people unconsciously make choices and decisions that express their feelings. Overconfidence in our safety will lead us to make unreasonably risky decisions. Kahneman explains that researchers "have observed that people who do not display the appropriate emotions before they decide….have an impaired ability to make good decisions. An inability to be guided by a "healthy fear" of bad consequences is a disastrous flaw" (6). This means that companies need to organize their ability to doubt. The sense of vulnerability will improve risk assessments and open our eyes to risky behavior that was previously accepted.

Reluctance to Simplify

Simplification is detrimental because it tends to close avenues for discussion and creates the kind of paradigm that was discussed earlier. Companies should simplify as late as possible to avoid the biases that inevitably come with a set paradigm (5).

The reluctance to simplify also fights against structural secrecy since it is counter to the formal communication efforts that are intended to streamline the communication process. Identifying failures becomes more common because the more one knows; the more one realizes the extent of his ignorance.

Sensitivity to Operations

The concept of sensitivity to operations requires understanding the actual effectiveness of a system regardless of designs and intentions. It requires leaders to maintain constant contact with the operating system and to be available when problems arise. It is a lack of sensitivity to operations that allows paradigms to persist. Operations gain a type of momentum where data is processed by rote without consideration given to new possibilities. Weick and Sutcliffe suggest that for momentum to be overcome, one has to slow or stop the normal processes; even to the point of creating interruptions (5). These interruptions are needed to allow people time to rethink, reorganize, and challenge the existing paradigm.

Commitment to Resilience

In this context, resilience describes one's ability to make sense of information encountered in an unexpected situation. An HRO must be committed to improving employee knowledge and ability to act during an emergency. Ideally, people must be experienced enough to act but willing to treat past incidents as somewhat irrelevant. Since each situation is unique, it is important to make new assessments prior to employing past tactics.

Deference to Expertise

Deference to expertise describes an individual's willingness to yield decisions to others because they know the limits of their own knowledge and experience (5). They realize that the core of the expert's role is to provide knowledge that we could attain for ourselves if we had enough time. An important aspect is that people understand that authority does not necessarily equate to expertise and that greater expertise is not always found as one goes higher in the organizational chart. For example, a Site Manager has the authority to make any risk decision but may not have the expertise to make a good decision. Companies must identify experts and develop avenues to allow decisions to flow to them.

Application of HRO Principles to Combat NoD

How do we apply these HRO principles to the three areas that contribute to Normalization of Deviance: the production of a work group culture, the culture of production, and structural secrecy? The production of work group culture is the cycle of signals, reviews, and acceptance of risk that industry most often describes as Normalization of Deviance. It is believed that this area is most likely to be controlled by a solid process safety program. Still, since these programs will never be 100% effective, companies should develop programs to break paradigms inherent in engineering culture and to offset the aspects inherent in structural secrecy.

Table 1 is a sampling of suggestions provided by Weick and Sutcliffe. It gives concepts that can be used to develop site programs. For example, using the premortem concept (7) in a Job Safety Analysis or as part of Management of Change could be an effective way to identify faulty paradigms. Structural secrecy seems to be a larger challenge because less communication and less simplification can be competing goals. Ultimately, it is up to each employee to be vigilant at seeking out and communicating bad news. The bearer of bad news needs to view his responsibility as an on-going alert rather than a one-time flare of concern.

At Albemarle, efforts to develop some of these concepts into a company-wide program have just begun. It is hoped that other companies will take these concepts and develop effective programs that can be shared within the chemical and refining industries to improve performance with respect to Normalization of Deviance.

Table 1: Improvement Concepts for High Reliability Organizations[5]

Engineering Culture
Preoccupation with Failure
Companies must establish preoccupation as a strategy. Instead of a strategy focusing on what the company wants to accomplish, focus on the errors that you don't want to make.
Consider a "premortem" – A premortem is a technique developed by Gary Klein where a work group meets, assume their project or organization has just experienced a disaster, then writes a brief history to describe how the event would have occurred.[6]
Reluctance to Simplify
Encourage healthy skepticism in your processes; it is a form of redundancy
Develop a culture where new evidence requires a revision of the paradigm.
Sensitivity to Operations
Encourage and reward people who speak up; including dissenting views.
Develop a culture that sees interruption as an opportunity rather than a nuisance.
Structural Secrecy
Preoccupation with Failure
Managers should make it a practice to ask employees, "What is the biggest risk in your process?" People need to be reminded that failure is possible.
Managers must seek bad news because it is not as likely to be communicated as good news.
Sensitivity to Operations
Reward managers who stay close to the operating system or frontline activities.
Deference to Expertise
Be aware of the "fallacy of centrality." This assumes that since you are in a central position if something serious were happening, you would know about it. And since you don't know about it, it isn't happening.
Do not inflate your own expertise and be wary of others who inflate theirs. Such people are less curious about the world and are more vulnerable to surprises. The mistaken claim that "nothing is happening" can be interpreted as no one was looking, asking, or listening.

[5] Unless otherwise noted, concepts gleaned from *Managing the Unexpected,* Weick and Sutcliffe

[6] Performing a Project Premortum, Klein, Harvard Business Review, Sept 2007

1. **Vaughan, Diane.** *The Challenger Launch Decision, Risky Technology, Culture, and Deviance at NASA.* Chicago : The University of Chicago Press, 1996.

2. **Presidential Commission.** *Report of the PRESIDENTIAL COMMISSION on the Space Shuttle Challenger Accident.* Washington, D. C. : s.n., 1986.

3. **Kuhn, Thomas.** *The Structure of Scientific Revolutions.* Chicago, IL : University of Chicago Press, 1996.

4. *Some Characteristics of One Type of High Reliability Organization.* **Roberts, K. H.** s.l. : Organization Science, 1990.

5. **Weick, Karl E. and Sutcliffe, Kathleen M.** *Managing the Unexpected, Sustained Performance in a Complex World.* New Jersey : John Wiley & Sons, Inc., 2015.

6. **Kahneman, Daniel.** *Thinking, Fast and Slow.* New York : Farrar, Straus and Giroux, 2011.

7. *Performing a Project Premortem.* **Klein, Gary.** 2007, Harvard Business Review.

Appendix A: Example of Glass Repair Matrix

Glass Repair Matrix

VESSEL SCORE

0

Vessel:	Vessel Description	Date:	8/25/2016
Funct. Loc.:	Functional Location		
Equipment:	SAP Equipment Number		

Patch Type	**Category Score**		**0**
Single Stud Patch		X	NO
Multistud Patch		X	NO
Nozzle Sleeve - Inside-Out type (Studless)		X	NO
Nozzle Sleeve - Inside-Out type (Multi-Stud)		X	NO
Nozzle Sleeve - Quickfix type		X	NO
Repair Size 2" or less		X	NO
Repair Size 6" or less		X	NO
Repair Size 8" or less		X	NO
Repair Size greater than 8"		X	NO
Epoxy Putty (i.e. Belzona, ProPoxy)		X	NO
Patch Location	**Category Score**		**0**
Vapor Space		X	NO
Liquid Space		X	NO
Single Radius		X	NO
Double Radius		X	NO
Bottom Nozzle		X	NO
Chemical Corrosivity	**Category Score**		**0**
Corrosive to Glass		X	NO
Non Corrosive to Steel (Under 10% of wall thk per year)		X	NO
Corrosive to Patch Material		X	NO
Corrosive to Patch Filler		X	NO
Age / Condition	**Category Score**		**0**
Old / Existing Repair		X	NO
Fire Glaze Gone		X	NO
Multiple Repairs		X	NO
Potential Risk	**Category Score**		**0**
Compromised Secondary Containment		X	NO
High Traffic Area		X	NO
High Risk Chemical (see Magnolia Policy EHS-1000)		X	NO
Reactive issues if Chemical mixes with Jacket Media		X	NO

The Vessel Score above is compared to a low/medium/high risk criteria with specific inspection and replacement criteria for each risk category.

Vessel Score **0** Date: 8/25/2016